DATA CENTER ENERGY BENCHMARKING

CASE STUDY, APRIL 2003

DATA CENTER FACILITY 5

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I. Definitions

Chiller Efficiency	The power used (kW), per ton of cooling produced by the chiller.
Measured Computer /Server Load Density	Ratio of actual measured Data Center Server Load in Watts (W) to the gross area (ft^2 or sf) of Data Center Floor Space. Includes vacant space in floor area.
Projected Computer /Server Load Density	Ratio of forecasted Data Center Server Load in Watts (W) to square foot area (ft^2 or sf) of the Data Center Floor if the Data Center Floor were fully occupied. The Data Center Server Load is inflated by the percentage of currently occupied space.
Computer Load Density – Rack Footprint	Measured Data Center Server Load in Watts (W) divided by the total area that the racks or equivalents occupy, or the rack "footprint".
Computer Load Density per Rack	Ratio of actual measured Data Center Server Load in Watts (W) per rack. This is the average density per rack.
Cooling Load Density	The amount of cooling (tons) supplied to a given floor space (Ton/ft^2 or sf)
Critical Load	Electrical load of equipment that must keep running in the event of a power failure. Such loads are typically served by an Uninterruptible Power Supply (UPS), which uses a bank of batteries to support the load when the normal source of power fails. The batteries can support the load for only a short period. In some facilities the equipment is shut down gracefully and turned off until normal power returns. In other facilities a backup generator, typically diesel-powered, comes on-line and provides power for a longer period of time.
Data Center Cooling	Electrical power devoted to cooling equipment for the Data Center Floor space
Data Center Facility	A facility that contains data storage and processing equipment (servers) associated with a concentration of data cables.
Data Center Floor / Space	Total footprint area of controlled access space devoted to company/customer equipment. Includes aisles, caged space, cooling units, electrical panels, fire suppression equipment, and other support equipment. This gross floor

	space is what is typically used by facility engineers in calculating a computer load density (W/sf).[1]
Computer Equipment Occupancy	This is based on an estimate on how physically loaded the data centers are by computer and equipment footprints. Some people use the term as "Data Center Occupancy."
Data Center Server/Computer Load	Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers, switches, routers, storage equipment, monitors, and other equipment.
Cooling Effectiveness Index	Ratio of electrical power devoted to cooling data space to the electrical power used by computer and equipment in Data Center Floor. A lower number corresponds to more effective cooling.
Cooling Load Tons	A unit used to measure the amount of cooling being done. Equivalent to 12,000 British Thermal Units (BTU) per hour.

[1] Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft2-gross) or gross watts per square meter (watt/m2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

II. Introduction

Rumsey Engineers and the Lawrence Berkeley National Laboratory (LBNL) have teamed up to conduct an energy study as part of LBNL's Data Center Load Characterization under sponsorship by the Federal Energy Management Program (FEMP). Measurements were conducted on-site in October of 2002, with the particular aim of determining the end-use of electricity of data center systems. This study may provide useful information for designers to consider in their decision-making for future design and construction of data centers. The identity of the organization that owns this data center is kept anonymous. The facility that houses the data center is referred to throughout this report as Data Center Facility 5.

This report will present energy density and the energy efficiency metrics evaluated for the case studies. The variety of mechanical system equipment, and data center types, coupled with the results of the data will provide insight into efficient cooling strategies for data centers. The goal of the project is to obtain benchmarking data and to identify energy efficiency opportunities and best practices.

III. Site Overview

Data Center Facility 5 is located in California's San Francisco Bay Area. The data center occupies 16,000 square feet (sf) of a 62,700 sf multi-level building. The data center houses servers (computer equipment), storage drives and a control room. It operates 24 hours a day with a small number of employees who work with the computers daily. The control room, situated within the data center is 800 sf and is used to troubleshoot and monitor the activity of the computers. The remainder of the building is used as office space.

During this study, the data center was under expansion. Measurements made reflect a data center area of 16,000 sf, which does not include the expansion. According to the building facilities manager, the space allocated to computer equipment in the data center was 60% occupied. The computer equipment and storage drives occupy 18% (2,900 sf) of the data center. The support equipment (i.e. air handlers, electrical power distribution units, and uninterruptible power supply) occupies 31% (5,000 sf) of the data center. The control room occupies 5% (800 sf) of the data center. The remaining 46% (7,300 sf) is either walkway space between the computer and support equipment, or unused floor space.

IV. Energy Use

ELECTRICAL EQUIPMENT AND BACKUP POWER SYSTEM

The requirement for high reliability of this facility was determined not to be critical in considering the associated costs and the best use of data center investment. Therefore, the use of UPS (uninterruptible power supply) systems for the computers in this data center is minimal. There are small UPS systems for the building's phone system and for a bank of computers in the data center. A UPS delivers "clean" power to computer equipment by filtering out voltage spikes and surges. A UPS continuously converts alternating current (AC) power to direct current (DC) power and charges a battery bank. DC power from the batteries is then converted back to AC power to feed the data center equipment. In the event of a power outage the battery bank supplies backup power for a specified time until power is restored or the computer is safely shut down. The UPS system for the computers has a 225-kVA capacity and is currently 10% loaded. Typically, UPS loaded lightly tend to be very poor in efficiency. Most of the computer equipment is served by power distribution units (PDUs) situated throughout the data center. The PDUs receive power from the main electrical distribution boards. Their purpose is to remove spikes and transients and to convert power to 120 Volts from 480 Volts.

COOLING SYSTEM

A chilled water system is utilized to cool the entire building, including the data center space. It is comprised of two Trane 800-ton, water-cooled centrifugal chillers, one of which has a variable frequency drive (VFD). Normally, the VFD-equipped chiller 1 runs with the non-VFD chiller 2 in standby. A third VFD-equipped chiller 3 being added is part of the buildout. The rated nominal efficiency of the VFD chillers 1 and 3 is 0.40 kW/Ton. The rated nominal efficiency of non-VFD chiller 2 is 0.42 kW/Ton.[2]

There are two, two-cell cooling towers with a 25 hp single-speed fan in each cell, supplied by two constant-speed 75 hp condenser water pumps. Normally, one pump operates at a time on a lead-lag schedule. The chilled-water pumping system employed is a constant-primary with variable-secondary loop. Normally, one 25 hp primary pump and one variable speed 60 hp secondary pump operates. There are identical primary and secondary pumps for backup that operate on a

[2] Based on 1920 gal per minute (gpm), entering and leaving chilled water temperatures of 55 °F, and 45 °F, respectively, and entering condenser water temperature of 75 °F.

lead-lag schedule. A third set of identical condenser and chilled-water pumps is being added as part of the buildout.

The data center is conditioned by twenty-one computer room air conditioners (CRAC) and a single air handler, AHU-2. An additional 7 computer room AHUs were added as part of the buildout. Another small unit, AHU-4, serves the network room just off the main computer floor. As part of the buildout, the small conference room served by AHU-3 is being merged with the network room. Air handler AHU-2 is used to supply outside air for ventilation requirements and to positively pressurize the data center. The CRAC units are supplied with chilled water and have variable speed drives on the fans that deliver the cooled air through the 3-foot raised floor. The CRAC units have been carefully distributed within the data center to maximize the delivery of conditioned air. They are not all situated along the perimeter of the data center as typically designed for data centers. Simply placing CRAC units along the perimeter of a data center could cause short-circuiting of the conditioned airflow, and result in warmer temperatures towards the inner space of a data center. In addition, the 3-foot raised floor allows for low air pressure drop when supplying the same airflow rate, hence lowers fan power to deliver the same airflow within a certain time frame.

Electrical consumption data from chilled water plant and the data center's HVAC equipment is listed in the table below. Measurements were made on all equipment served with chilled water; either with data collected through the automated control system or with field attached equipment. Please refer to the Appendix for graphs of the measurements over the entire monitored period.

TABLE 1. COOLING EQUIPMENT ELECTRICAL AND LOAD MEASUREMENTS

Equipment	Spot / Calculated	Date	Units	Measurement
Chiller Power	Spot	10/25/02	kW	118
Chiller Tonnage	Spot	10/25/02	Ton	293
Pump Power	Spot	10/25/02	kW	94
CRAC Unit Power	Spot	10/25/02	kW	61
AHU-2 Power	Spot	10/25/02	kW	0.25

It was necessary to identify the load solely to the data center, in order to segregate the chilled water plant power consumption attributed to cooling the data center (please see the following table).

TABLE 2. DATA CENTER COOLING EQUIPMENT ELECTRICAL AND LOAD MEASUREMENTS

Equipment	Spot / Calculated	Date	Units	Measurement
Chiller Tonnage attributed to Data Center	Calculated	10/25/02	Ton	256.3
CRAC Unit Tonnage	Calculated	10/25/02	Ton	255.6
AHU-2 Tonnage	Calculated	10/25/02	Ton	0.6
Chiller Power attributed to Data Center	Calculated	10/25/02	kW	103
Cooling Tower Fan Power attributed to Data Center	Calculated	10/25/02	kW	9
Pump Power attributed to Data Center	Calculated	10/25/02	kW	82

The load that the CRAC units and AHU-2 delivered to the data center was 87% of the chiller's entire load. This stipulates that a majority of the heat load within the building is generated from the data center. On October 25, 2002, the outside air temperature during the day was 60 °F on average. Due to the mild outdoor air conditions, the office spaces were demanding a small load of only 37 tons from the chilled water, the remainder being supplied by the outside-air economizer.

LIGHTING

Lighting in the data center consists of ceiling-mounted, troffer-type fluorescent fixtures. All lights were fully on when taking a spot power measurement. The spot measurement of the data center lighting power indicated approximately 16 kW when all lights are on. The actual lighting power may change over time because there are different schedules.

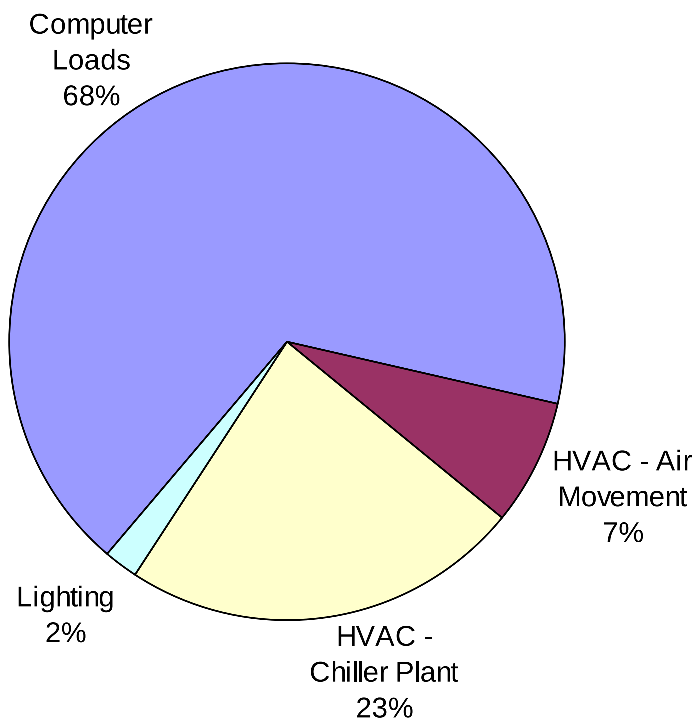
SUMMARY OF MEASUREMENTS AND METRICS

The table below shows the exemplar power consumption of HVAC and lighting equipment in the data center, which is also shown graphically in the pie chart below.

TABLE 3. DATA CENTER ELECTRICAL POWER USAGE

Computer Loads	565	kW	68%
HVAC - Air Movement	61	kW	7%
HVAC - Chiller Plant	194	kW	23%
Lighting	16	kW	2%

FIGURE 1. DATA CENTER ELECTRICAL CONSUMPTION



The computer loads amount to 68% of the data center power usage. Pumping and cooling of the chiller systems is the second largest consumer at 23%, with air movement at 7% as the next largest. Together, the HVAC components amount to 30% of the data center's power usage. Lighting accounts only 2% of the total power usage.

The electrical and cooling loads can be represented by different metrics. The most commonly used metric among data center facilities is the computer load density in watts consumed per square foot. However, this square footage used is not consistent between designers and is a source of problems.[3] The Uptime Institute's definition of "Data Center Floor Area" includes the entire area that is dedicated to data center equipment. This

[3] See "Data Center Power Requirements: Measurements from Silicon Valley", by Mitchell-Jackson, Koomey, Nordman, & Blazek, December 2001. It is available on the web at http://enduse.lbl.gov/Info/Data_Center_Journal_Articl2.pdf.)

includes rack spaces, storage areas, aisles, and areas utilized for power distribution and CRAC units. This definition is however basically subjective. Some data centers use kVA/rack or kW/rack as a design parameter. We have also calculated the W/sf based on the rack area alone. In addition to the previous metrics, the “non-computer” power densities are calculated, based on the “data center floor area”. The “non-computer” items include the equipment such as HVAC, and lighting. In addition, based upon actual 60% computer and equipment occupancy in the data center, the projected computer load density at otherwise 100% occupancy can be estimated.

TABLE 4. DATA CENTER ELECTRICAL CONSUMPTION METRICS

Data Center Floor Area	16,000	sf
Rack Area	2,880	sf
Data Center Occupancy	60	%
Based on Data Center Floor Area:		
Computer Load Density	35	W/sf
Non-Computer Load Density	17	W/sf
Projected Computer Load Density	59	W/sf
Based on Rack Area:		
Computer Load Density	196	W/sf
Projected Computer Load Density	327	W/sf

The computer load density based on the “data center floor area” (gross area) is 35 W/sf. At full occupancy, the computer load density is projected to be 59 W/sf. The computer load density based on “rack area” is presently 196 W/sf, and is projected to be 327 W/sf at full occupancy. The non-computer load (or power) density, which includes HVAC and lighting is 17 W/sf.

Since the loading of data centers and computer types are site specific, a more useful metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power. The “Cooling Effectiveness Index ” is 0.45 kW/kW (a lower number corresponds to more effective cooling, see Table 5). This indicates that in Data Center 5 for every unit of power used by computer equipment, 45% of the cooling power is being called for to maintain the conditions of the data center.

Although there is a small amount of cooling load generated from the presence of human activities, the load is insignificant compared to the computer loads. The more traditional metrics of power per ton of cooling (kW/Ton) are calculated for total HVAC efficiency (chillers, pumps, and air handlers), and for the chillers.

TABLE 5. HVAC EFFICIENCY METRICS

	Value	Units
Cooling kW: Computer Load kW	0.45	--
Cooling Provided by Chilled Water System	293	Tons
Chiller 2 Efficiency	0.4	kW/ton
Chiller 2 Design Efficiency	0.4	kW/ton

Chiller ARU-2 was operating close to the full-load efficiency it was designed for. Constant speed chillers typically operate at poor efficiencies at part load. However, the measured efficiency is positively impacted by a lower condenser water temperature which is lower than the designed water temperature.

V. Energy Efficiency Recommendations

As a result of this study, the team was able to identify energy efficiency opportunities for the facility. The trended data in particular reveals the operation of the mechanical equipment and if the equipment is operating as intended.

TUNE CONTROLS FOR AHU-2

The air handler serving the data center, AHU-2 is excessively cycling between heating and cooling modes. A figure of the unit's temperatures and valve positions can be seen in the Appendix. Tuning of the controls is recommended for the air handler to minimize the cycling between heating and cooling.

INVESTIGATE AHU-5

The air handler serving the telephone equipment room, AHU-5 is overcooling the space. The set point of the space was designed for 75°F. During the monitoring period, the unit was continuously running with an average return air temperature of 64 °F.[4] This implies that the room temperature is 64°F. The potential culprit of this wasted energy is likely to be the room temperature sensor or a control problem.

[4] Return air temperature was measured at the return air path of the air handling unit, AHU-5.

LIGHTING CONTROL FOR DATA CENTER AND EQUIPMENT ROOMS

The data center is sparsely occupied during business hours. It has even lower or no occupancy after normal business hours.

In each of the two largest basement equipment rooms, a portion of the lights is currently controlled with an on/off switch while the remainder stays on continuously. Lights in the equipment rooms are typically left 100% on by the occupant(s) of the rooms since on/off toggle switches are utilized. Adding timer switches for the controlled lighting was a recommendation made by the mechanical systems technician. By replacing the switches with timer switches, lighting power consumption can be reduced in this 24-hour operated facility. An occupancy sensor switch is an alternative, however, multiple sensors may be desired due to the obstructions in the rooms. Installing multiple overhead occupancy sensors for lighting control would ensure that the lights remain on when a person is working with the computer equipment.

RAISE CHILLED WATER TEMPERATURE

Other operating conditions remaining the same, a chiller that produces chilled water with warmer water temperature would normally operate more efficiently. It is possible that the chilled water (CHW) temperature can be raised from the current 45°F to somewhere in the range of 50°F to 55°F. During the study, the chiller was only 37% loaded, indicating that the control valves on the CRAC and air handler’s cooling coils were only partially open. By raising the CHW temperatures, the valves should open more fully to allow more CHW flow through the coils. In addition, energy savings can be achieved by improving chilled water temperature control and improving performance monitoring and tracking.

The dehumidifying control in the data center has been disabled, which indicates there probably is no practical need for chilled water temperatures as low as 45 °F. However, humidity requirements for the office spaces should also be evaluated.

FREE COOLING

Free cooling can be achieved by displacing the chillers and using the cooling towers to produce water around 50°F when outdoor wet bulb temperatures are relatively low, e.g., below 45°F. This measure can be directly related to the recommendation above, “Raise Chilled Water Temperature.” A retrofit would be necessary to implement free cooling. During the year, free cooling can be utilized for 1,260 hours. For a chiller running at an average of 150 kW for 1,260 hours, 189,000 kWh will be consumed. Significant energy savings could be achieved when using the low-energy free cooling strategy. Consider water side economizer so that more efficiency could be attained. The economics of implementing a free cooling system should however be examined carefully. In addition, improve cooling tower controls by using variable or multi-speed motors on tower fans and pumps.

VARIABLE-PRIMARY ONLY PUMP RETROFIT

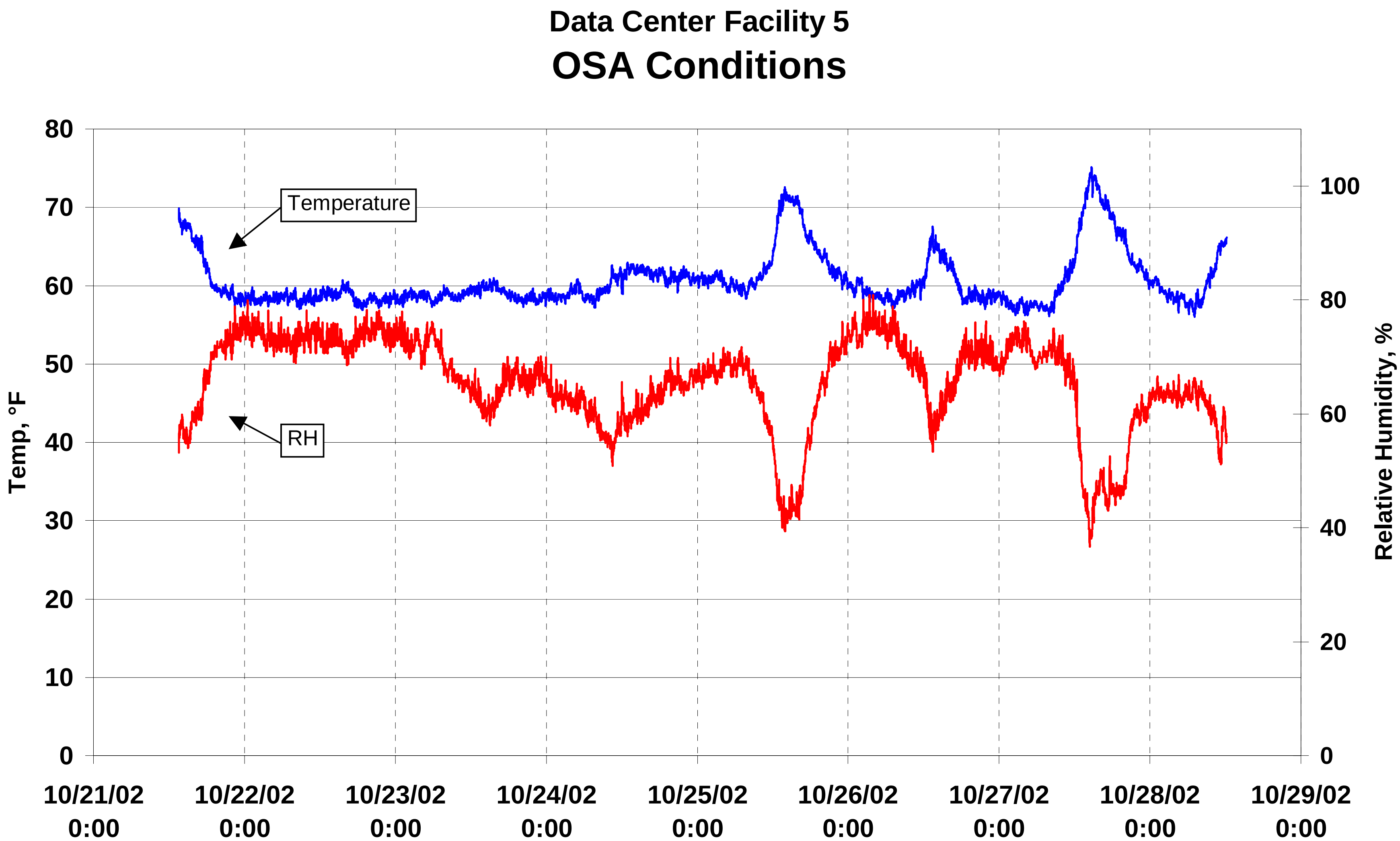
The chilled water distribution is configured in a constant-primary with variable-secondary loop. The cumulative pumping power was determined to be 94 kW during the monitoring period. This was equal to 80% of the chiller power at 118 kW. Retrofitting the current configuration with a variable-primary only pumping system may create pumping energy savings. The existing pressure transducer used to control the secondary pump speed can be reused to implement the variable-primary only pumping system.

It is worthwhile to investigate the current pumping set points and control in AHUs to avoid unwanted bypass.

COMMISSIONING AND CONTROL IMPROVEMENT

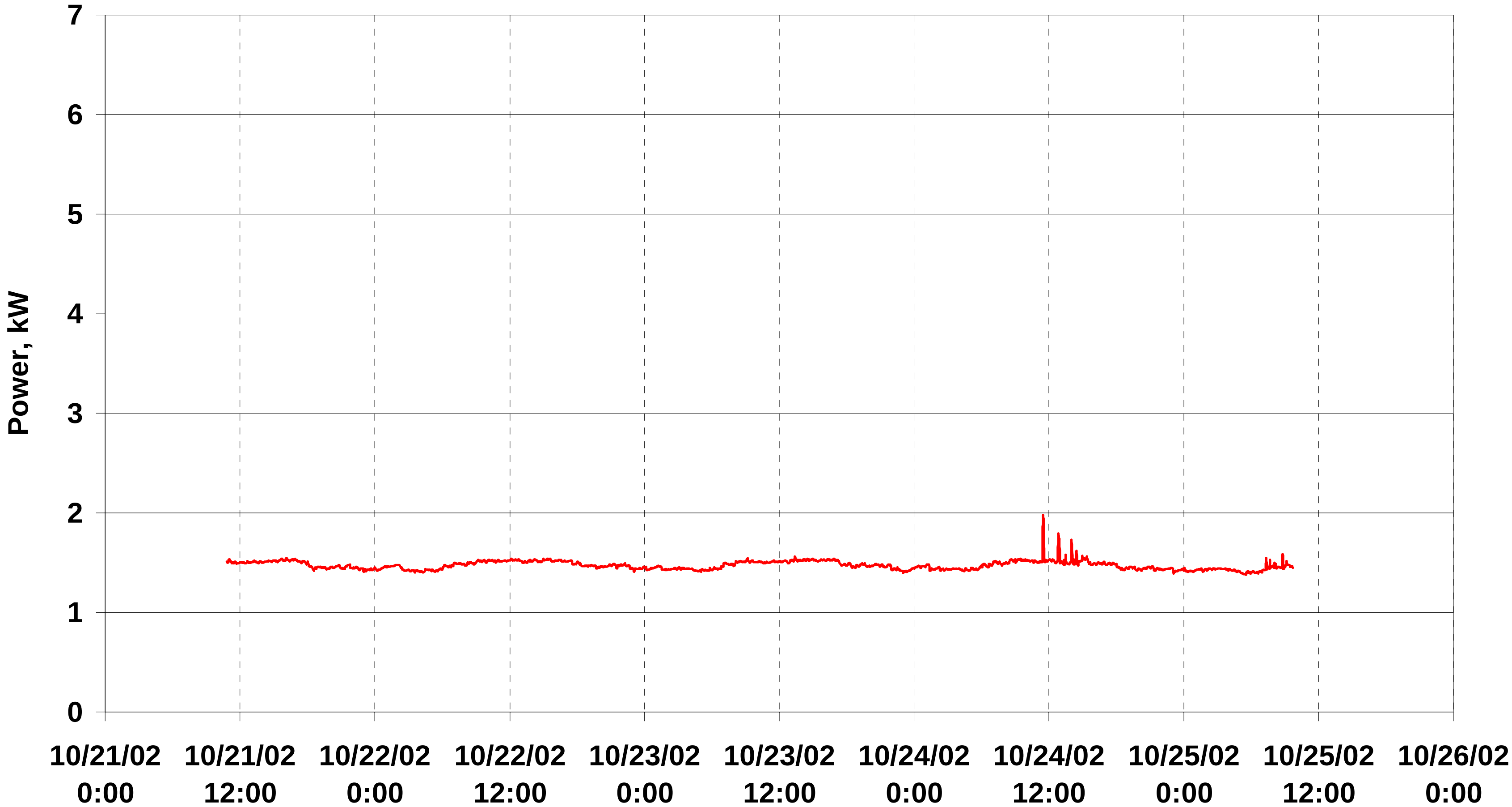
The improvement in commissioning, monitoring sensors (e.g., regular calibrations and additions where desired), re-heat control in AHU systems, and airflow control would add to the efficiency gains. To improve air management such as efficient VFD motors of CRACs and optimized distribution of CRAC units also helps to increase efficiency.

Appendix A – Monitored Data


Data Center Facility 5
OSA Conditions
Temp, °F
Relative Humidity, %
Temperature
RH
80
70
60
50
40
30
20
10
0
100
80
60
40
20
0
10/21/02 0:00
10/22/02 0:00
10/23/02 0:00
10/24/02 0:00
10/25/02 0:00
10/26/02 0:00
10/27/02 0:00
10/28/02 0:00
10/29/02 0:00

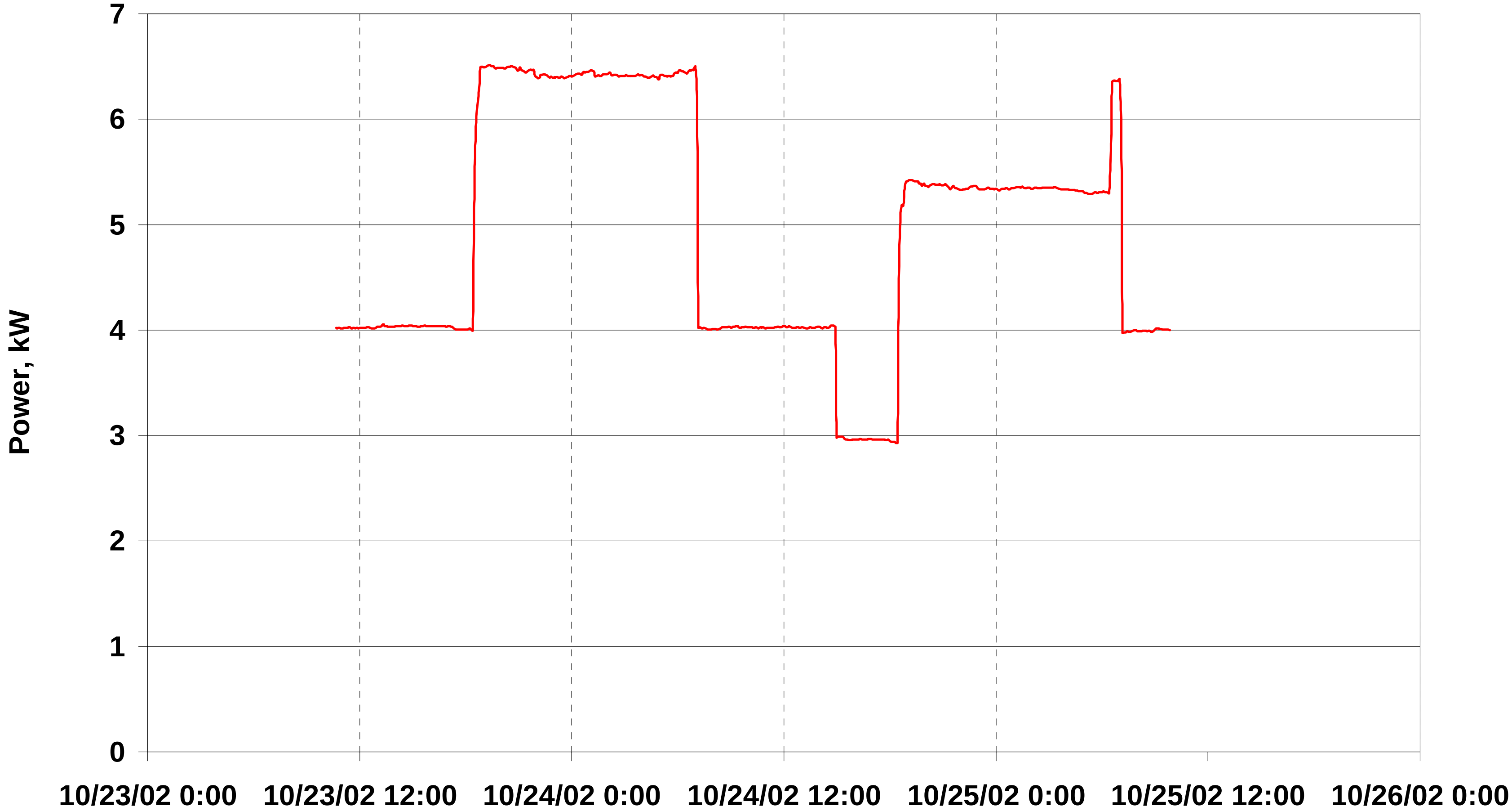
Data Center Facility 5

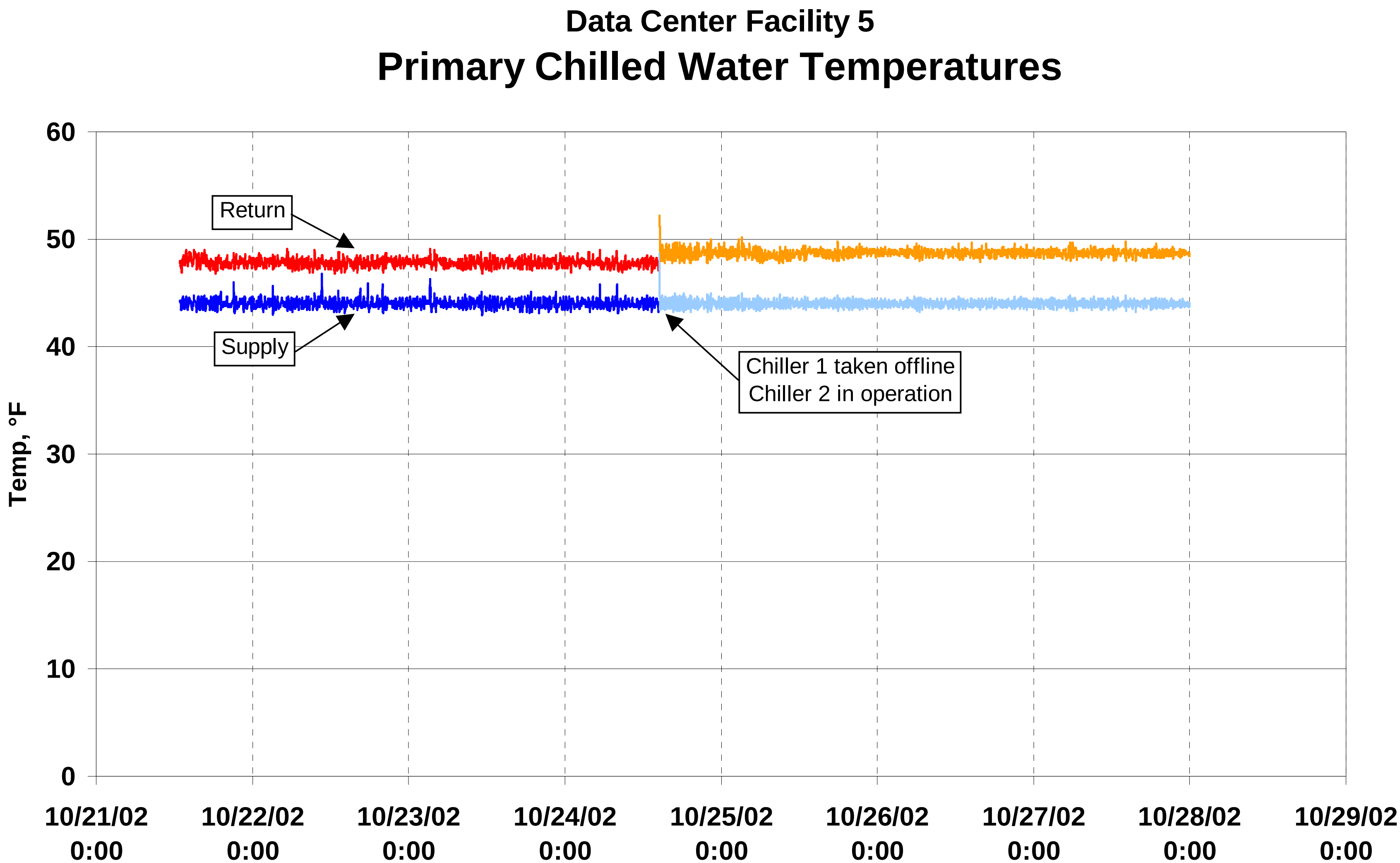
Transformer 529A Power (Office Plug Loads)

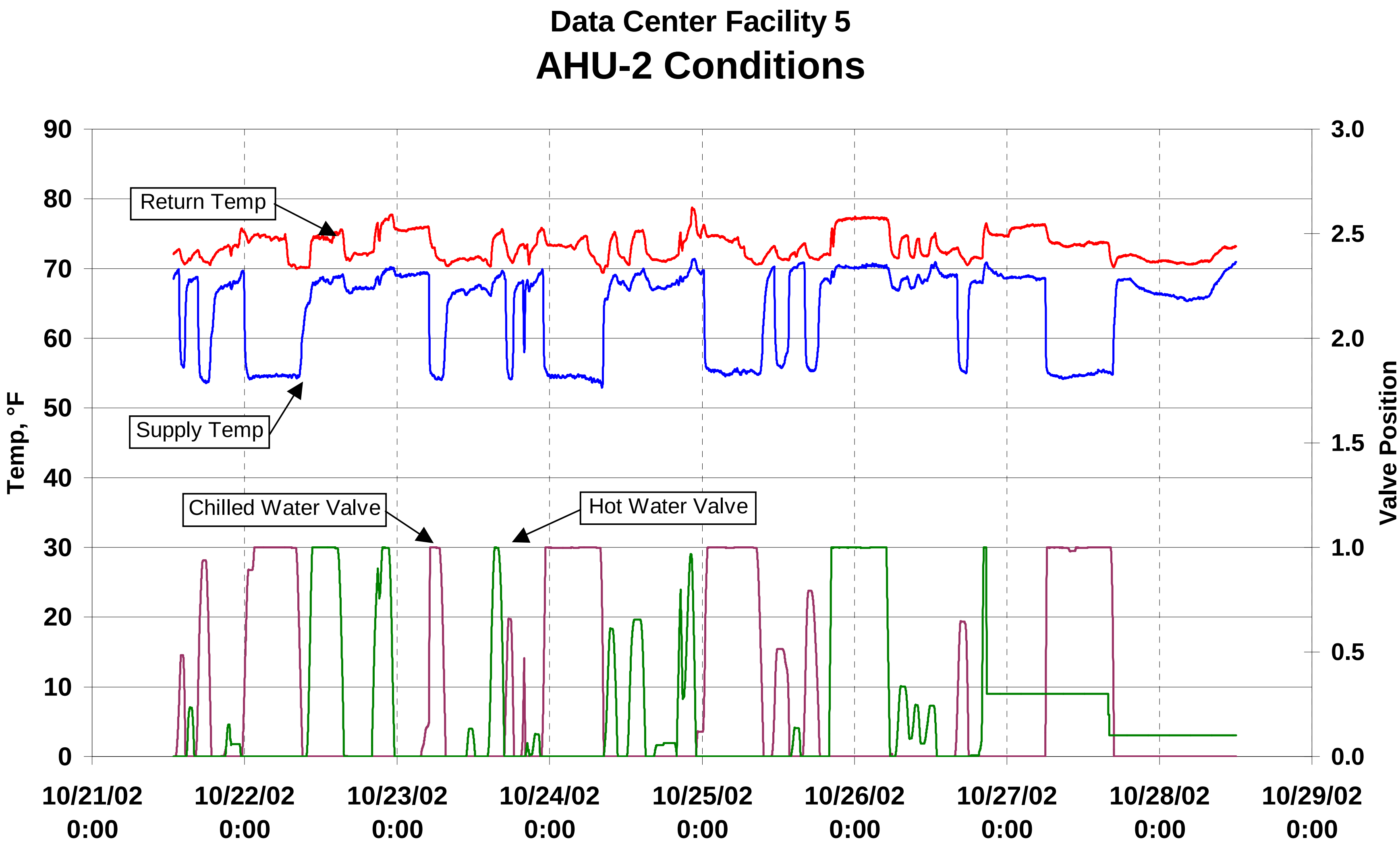


Data Center Facility 5

Panel 526A2A Power (Equipment Room and Misc Lighting)




Data Center Facility 5
Primary Chilled Water Temperatures
Temp, °F
60
50
40
30
20
10
0
Return
Supply
Chiller 1 taken offline
Chiller 2 in operation
10/21/02 0:00
10/22/02 0:00
10/23/02 0:00
10/24/02 0:00
10/25/02 0:00
10/26/02 0:00
10/27/02 0:00
10/28/02 0:00
10/29/02 0:00



Data Center Facility 5
AHU-2 Conditions
Return Temp
Supply Temp
Chilled Water Valve
Hot Water Valve
Temp, °F
Valve Position
90
80
70
60
50
40
30
20
10
0
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/21/02 0:00
10/22/02 0:00
10/23/02 0:00
10/24/02 0:00
10/25/02 0:00
10/26/02 0:00
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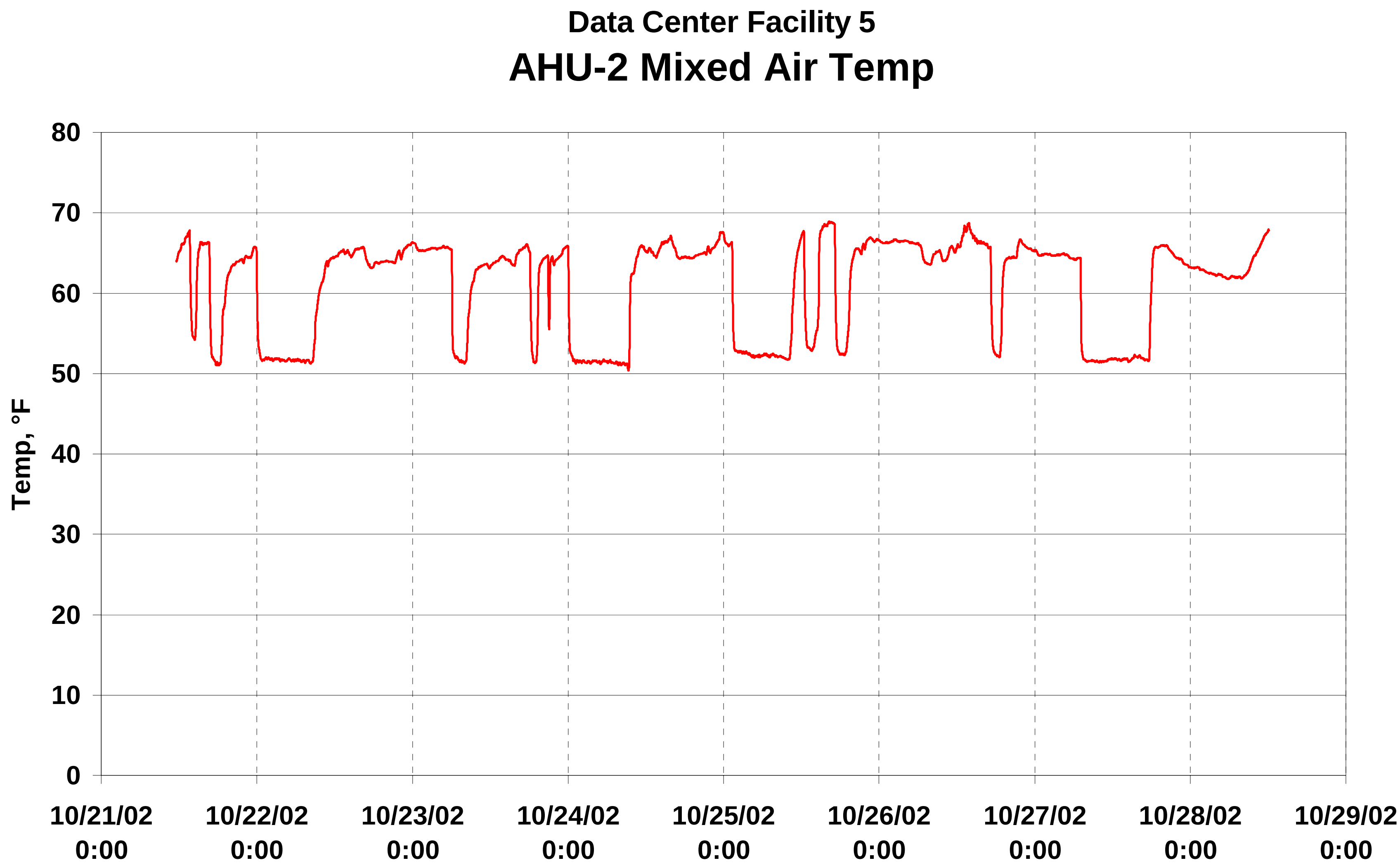
10/28/02 0:00
10/29/02 0:00


Data Center Facility 5
AHU-2 Mixed Air Temp
Temp, °F
80
70
60
50
40
30
20
10
0
10/21/02 0:00
10/22/02 0:00
10/23/02 0:00
10/24/02 0:00
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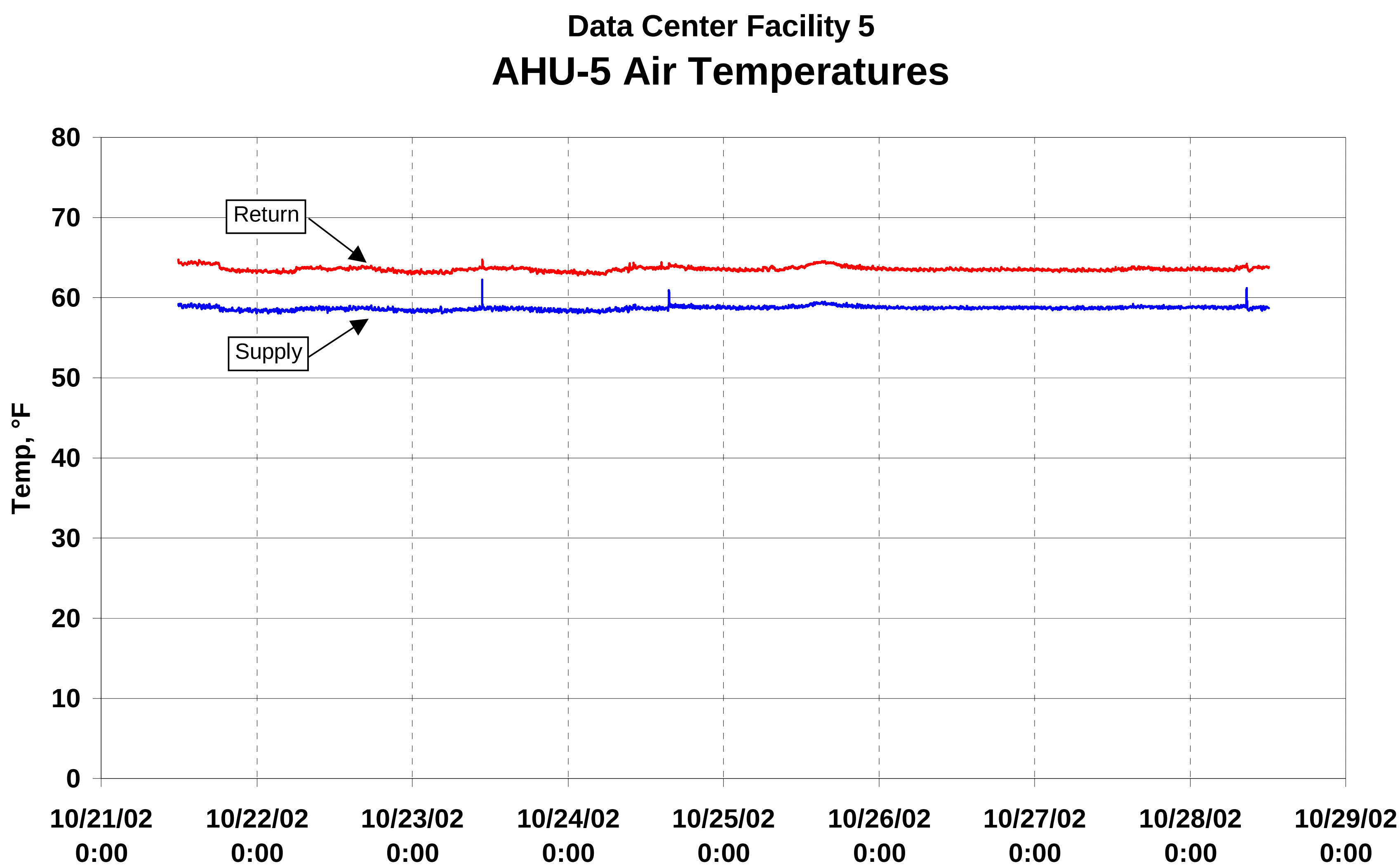
10/29/02 0:00


Data Center Facility 5
AHU-5 Air Temperatures
80
70
60
50
40
30
20
10
0
Temp, °F
Return
Supply
10/21/02 0:00
10/22/02 0:00
10/23/02 0:00
10/24/02 0:00
10/25/02 0:00
10/26/02 0:00
10/27/02 0:00
10/28/02 0:00
10/29/02 0:00